Aerosol Polarimetry Sensor (APS)

Design Summary, Performance and Potential Modifications

Brian Cairns
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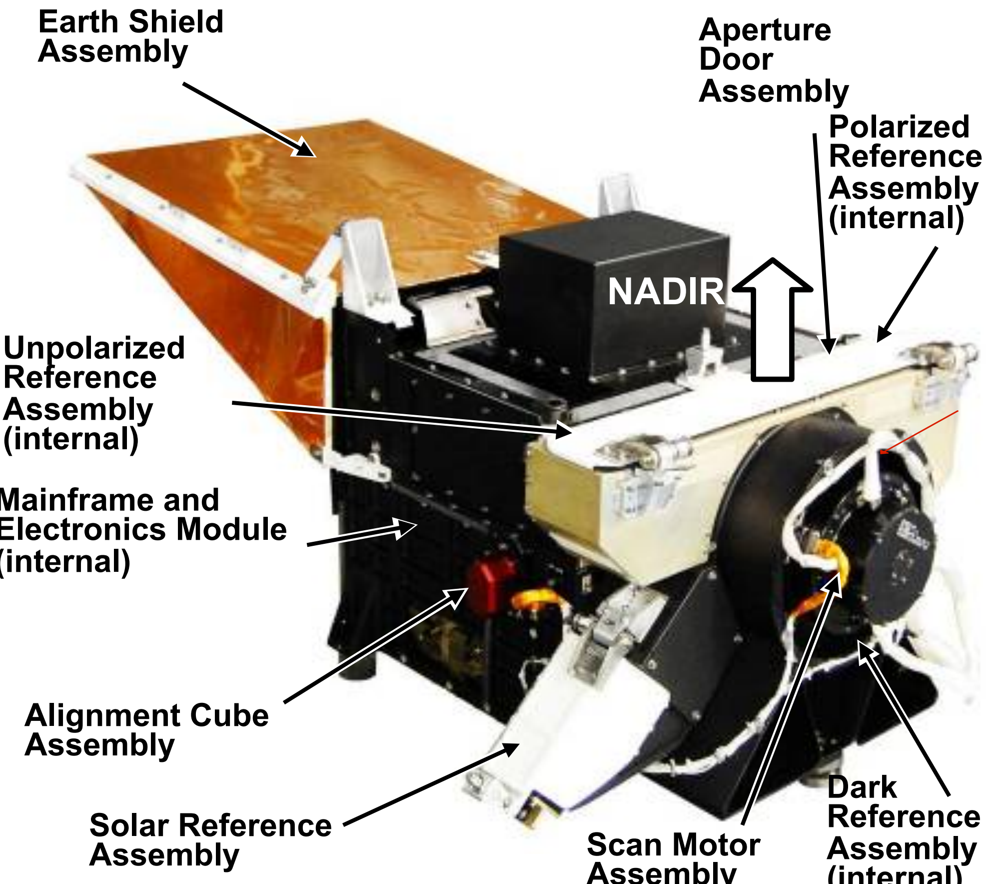
Technology Readiness Level Assessment

- Successful completion of vibration, acoustic, EMI/EMC and thermal/vacuum (1232 APS operational hours) testing at both the sensor and spacecraft level per GEVS.
- Documented by APS Pre-Ship Review Package and Glory Pre-Ship Review Package together with RVM and other requirements verification documentation.
- TRL level was assessed to be 7.

APS Description

MLI Blankets not shown



- **The APS instrument description**
  - Size: 48 cm x 61 cm x 112 cm
  - Weight: 61kgs (134.2 lbs)
  - Operational Power: 55.0 Watts
  - The APS instrument scans the earth over a nominal field-of-view of +50/-60 degrees about Nadir
  - The APS instrument generates along-track, multiple angle radiometric and polarimetric data with a 5.6 km (8 mrad) circular IFOV
  - APS collects data simultaneously in nine VNIR/SWIR spectral bands and four polarization states
  - APS includes four on-board calibration sources to maintain high polarimetric and radiometric accuracy on-orbit

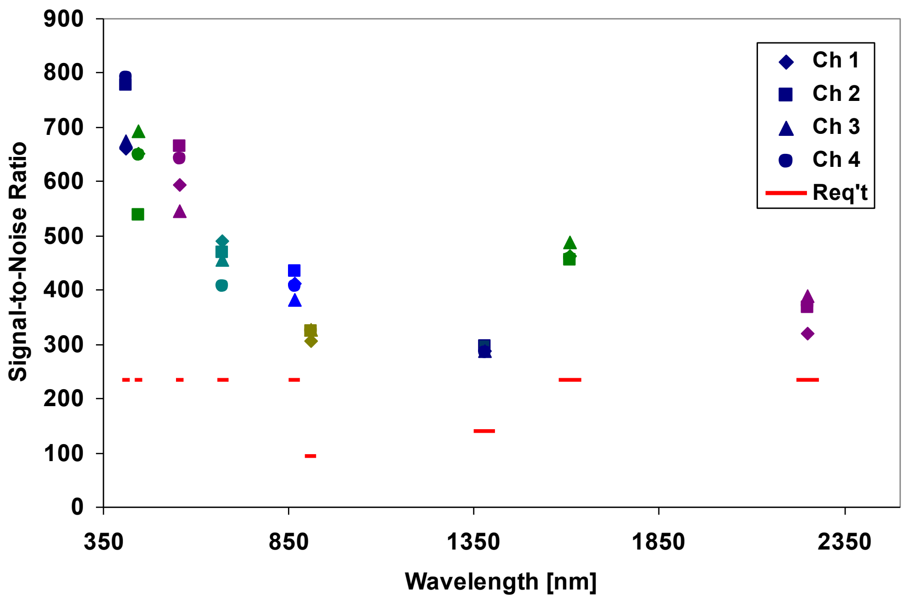
APS Performance

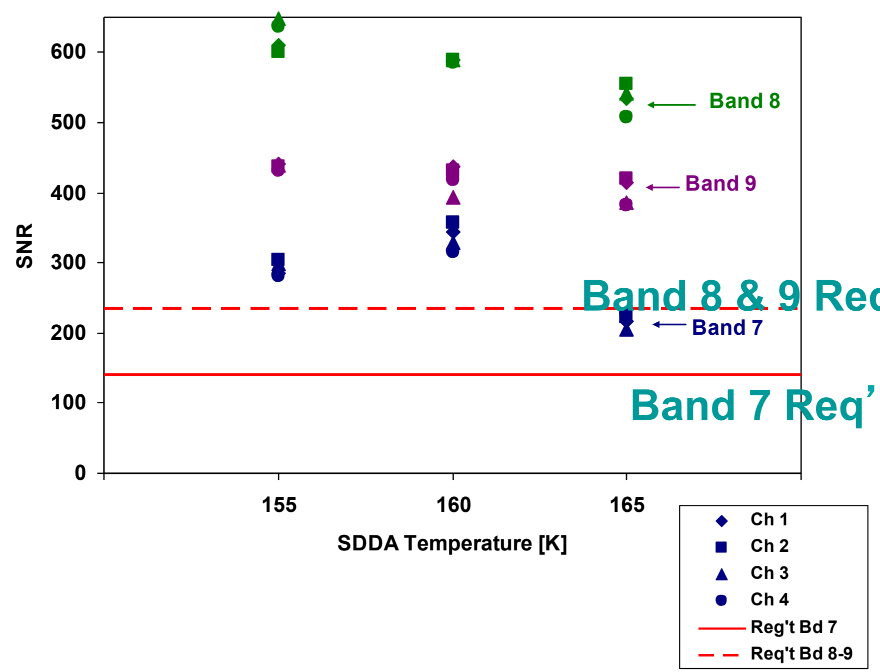
Signal-to-Noise Ratio

Results: SNR

- Data (TP-241 Section 5.2.1):
  - 27 SIS levels
  - 100 scans at each level without linear Attenuator
- Analysis performed using Verification Analysis Tool (SNR.Scanning.xmcd)
  - Calculate scene, dark, and fixed noise terms and combine to compute SNR

Band	Wavelength [nm]	Req't	Channel			
			1	2	3	4
1	412	235	662	779	674	792
2	443	235	652	539	692	649
3	555	235	593	666	546	643
4	672	235	491	469	456	407
5	865	235	412	435	382	408
6	910	94	306	324	327	324
7	1378	141	287	297	288	285
8	1610	235	463	456	488	457
9	2250	235	321	368	388	370





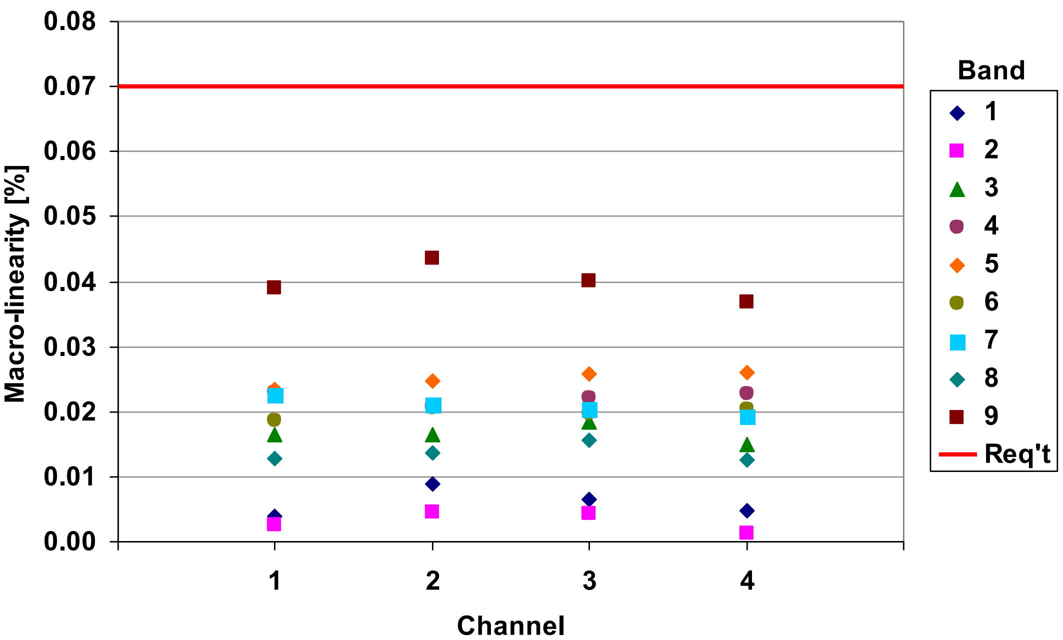
APS Performance

Linearity

- **Analysis used ratios of Attenuator-In to Attenuator-Out, perform fitting to ratios, evaluate residuals**

APS Macrolinearity [%]

Band	Req't	Channel			
		1	2	3	4
1	0.07	0.004	0.009	0.006	0.005
2	0.07	0.003	0.005	0.004	0.001
3	0.07	0.017	0.016	0.018	0.015
4	0.07	0.023	0.021	0.022	0.023
5	0.07	0.023	0.025	0.026	0.026
6	0.07	0.019	0.021	0.020	0.020
7	0.07	0.023	0.021	0.020	0.019
8	0.07	0.013	0.014	0.016	0.013
9	0.07	0.039	0.044	0.040	0.037



APS Performance

Absolute Radiometric Accuracy

- Analysis used data taken during performance testing and was verified over environments
  - 27 integrating sphere levels acquired consisting of both calibration and test levels
  - SDDA temp = 160K
  - Nominal integration time
  - No scrambler, no attenuator in optical path
  - Calculate relative (K_1, K_2, C_{12}), absolute (C_0) radiometric gain coefficients, compute estimated radiance for test levels, compare to SIS radiance and compute sensor error. Error tree used to compute system ARA.

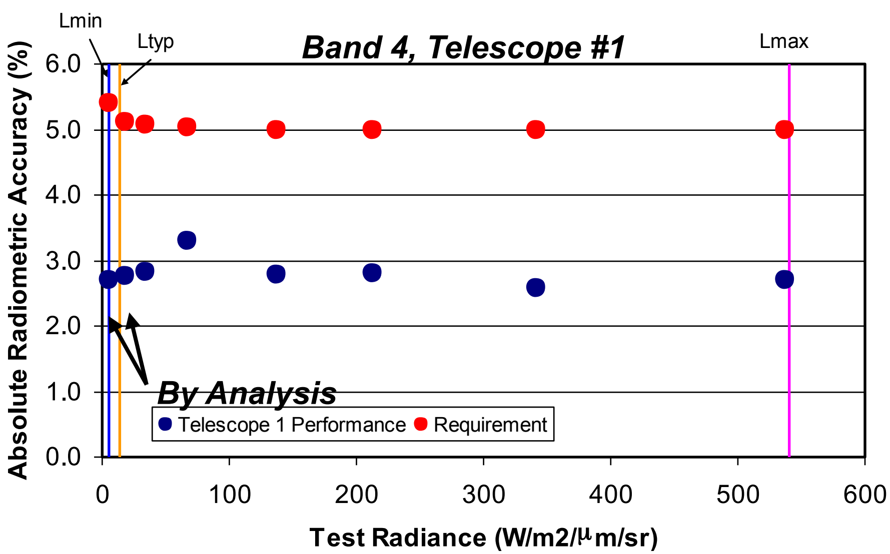
ARA [%]

Band	Req't	Telescope #1			Telescope #2		
		Lmin	Ltyp	Lmax	Lmin	Ltyp	Lmax
1	5%+2/S	2.5	2.5	2.5	2.5	2.5	2.5
2	5%+2/S	2.5	3.1	2.6	2.5	3.1	2.6
3	5%+2/S	2.8	2.7	2.6	2.9	2.8	2.8
4	5%+2/S	2.7	2.7	2.7	2.6	2.6	2.6
5	5%+2/S	2.8	2.8	3.2	2.8	2.8	3.2
6	5%+2/S	2.8	2.8	2.8	2.8	2.8	2.8
7	8%+2/S	4.9	4.3	4.3	5.0	4.4	4.4
8	5%+2/S	4.6	4.4	4.4	4.7	4.4	4.4
9	5%+2/S	5.2	4.2	4.1	5.2	4.2	4.2

VNIR radiances adjusted for lamp drift

Verification was demonstrated through a combination of test and analysis because of integrating sphere uncertainties at lower end of dynamic range

Example Absolute Radiometric Accuracy vs. Radiance

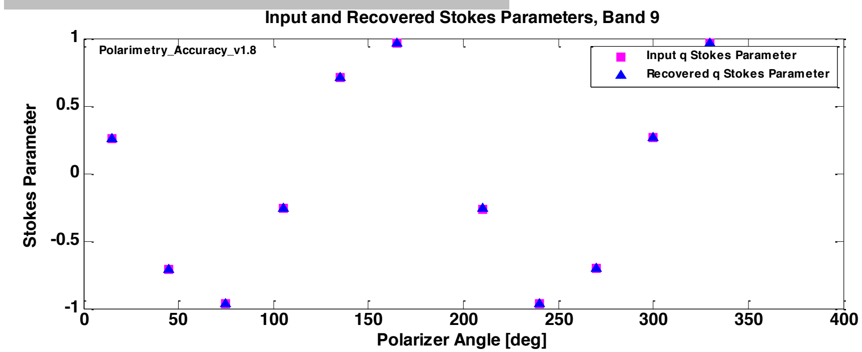


APS Performance

Polarimetric Accuracy

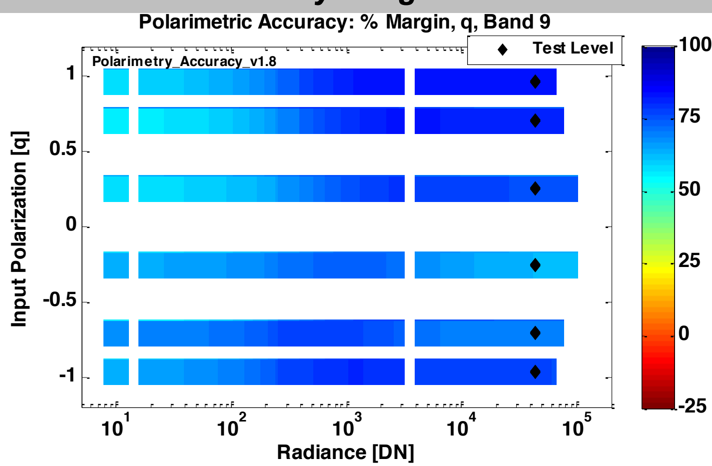
- Same data and analyses described on previous slide

Calibrated Stokes Parameters

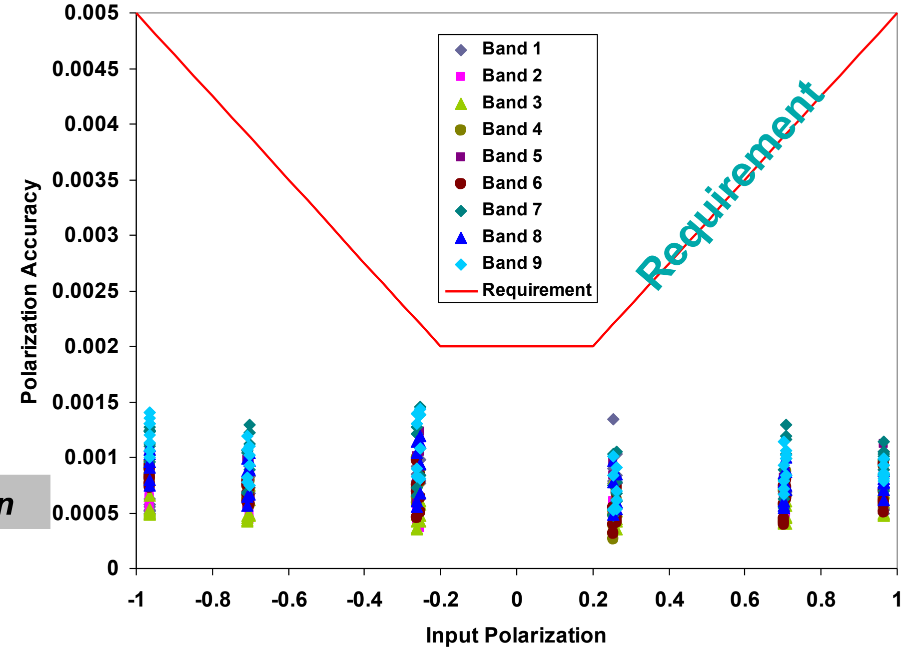


Application of calibration algorithm with measured coefficients accurately recovers input polarization state

Polarization Accuracy Margin vs. Radiance and Polarization



Polarization Accuracy at Test Radiances



Results consistent with ODM test results

Errors well below requirements

Polarimetric Accuracy met requirements over dynamic range and input polarization states

APS Assembly

Signal Processor Digital CCA
12 non-vac thermal cycles

Signal Processor Analog CCA
12 non-vac thermal cycles

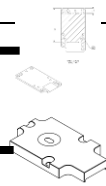
Scan Controller CCA (Pri & Rdt)
12 non-vac thermal cycles

Digital Processor CCA (Pri & Rdt)
12 non-vac thermal cycles

Auxiliary - Power Supply Assembly
12 non-vac thermal cycles

Electronics Module
Sine Burst
Sine Vibration
Random Vibration
1 non-vac thermal cycles

APS Assembly

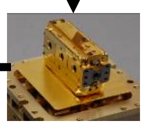


Pedestal SWIR Focal Plane Assembly
Sine Burst
Cover, Module, SWIR Detector Module

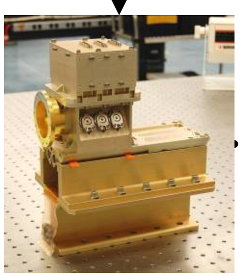
SWIR Detector Module Assembly (SDA)
Random Vibration
1 thermal-vac cycle

Mount, Detector Module, SWIR Dewar
Sine Vibration

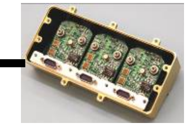
Isolator Assembly, Cold Stage, SWIR Dewar
Static Loads



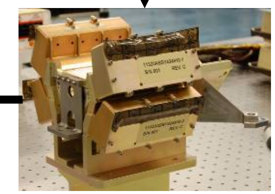
SWIR Dewar Base Assembly (SDBA)
Sine Vibration (includes Thermal Link)
Random Vibration (includes Thermal Link)



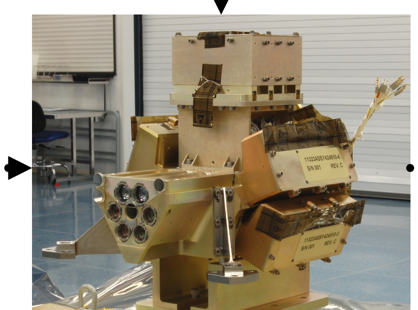
SWIR Optics & Dewar Assembly (SODA)



VNIR Detector Assembly (VDA)

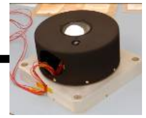


VNIR Optics & Detectors Assembly (VODA)

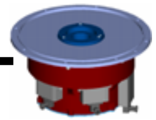


Optics & Detectors Module (ODM)

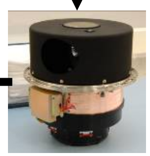
APS Assembly



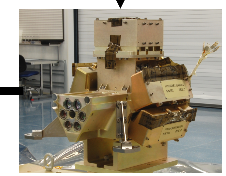
Scan Mirror Rotating Assembly (SMRA)
Sine Burst



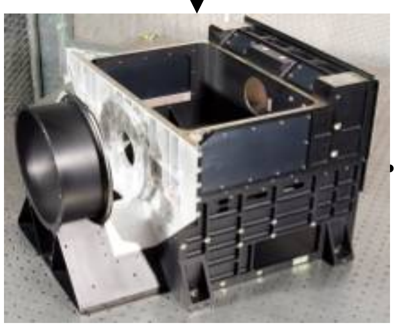
Scan Mirror Motor/Encoder Assembly (SMMA)
Sine Vibration
Random Vibration
Life Test
3 thermal-vac cycles

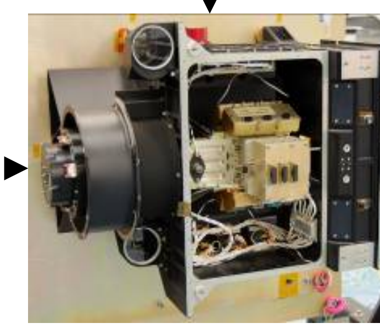


Scan Mirror Assembly (SMA)

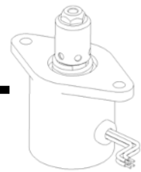


Optics & Detectors Module (ODM)



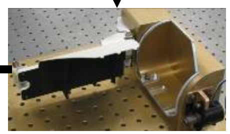


APS Assembly



Ejector Actuator Assembly
Life Test

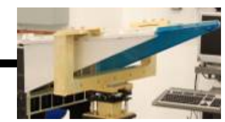
Bipod Assembly, Radiative Cooler
Static Loads



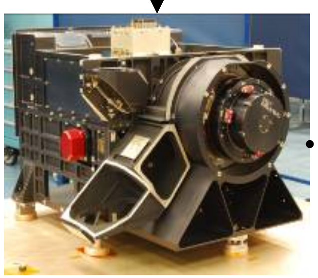
Solar Reference Door Assembly (SRDA)
Mechanical Functions
6 non-vac thermal cycles

Cryoradiator Assembly (CA)

Aperture Door Assembly (ADA)
Mechanical Functions
6 non-vac thermal cycles



Panel Assembly, Earth Shield
8 non-vac thermal cycles

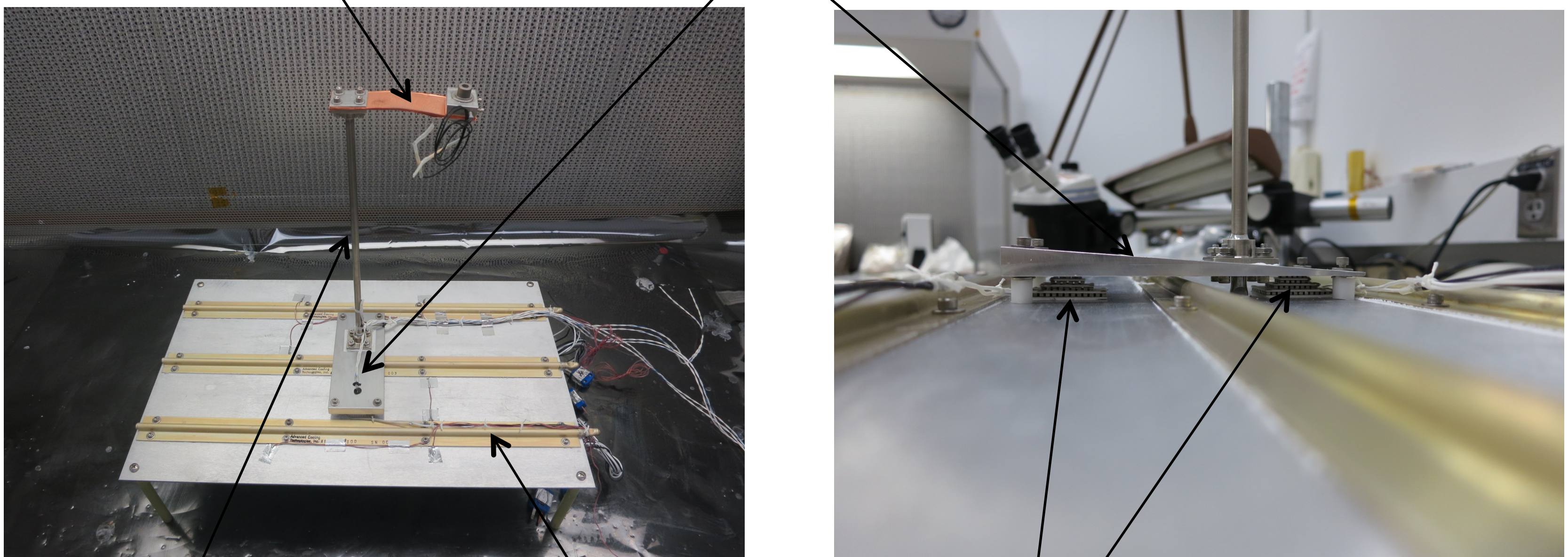


Polarimeter Module

APS Modification

- **Active cooling using a TEC provides greater flexibility in terms of accommodations than a passive cooler**
- Aluminum radiator plate (40.64 cm x 25.3 cm x 0.203 cm) with white paint
- Radiator has three Advanced Cooling Technologies ammonia heat pipe spreaders mounted to backside
- Two Marlow Industries 4-stage thermoelectric coolers (TECs) are attached to backside of radiator to increase contact area and reduce temperature gradient
- A small aluminum cold plate is bonded to cold side of TECs and thermally isolated from radiator by G10 standoffs
- One end of an Advanced Cooling Technologies ethane heat pipe is mounted to TEC cold plate, and the other end is mounted a copper strap (flexible linkage to detector assembly)

APS Modification

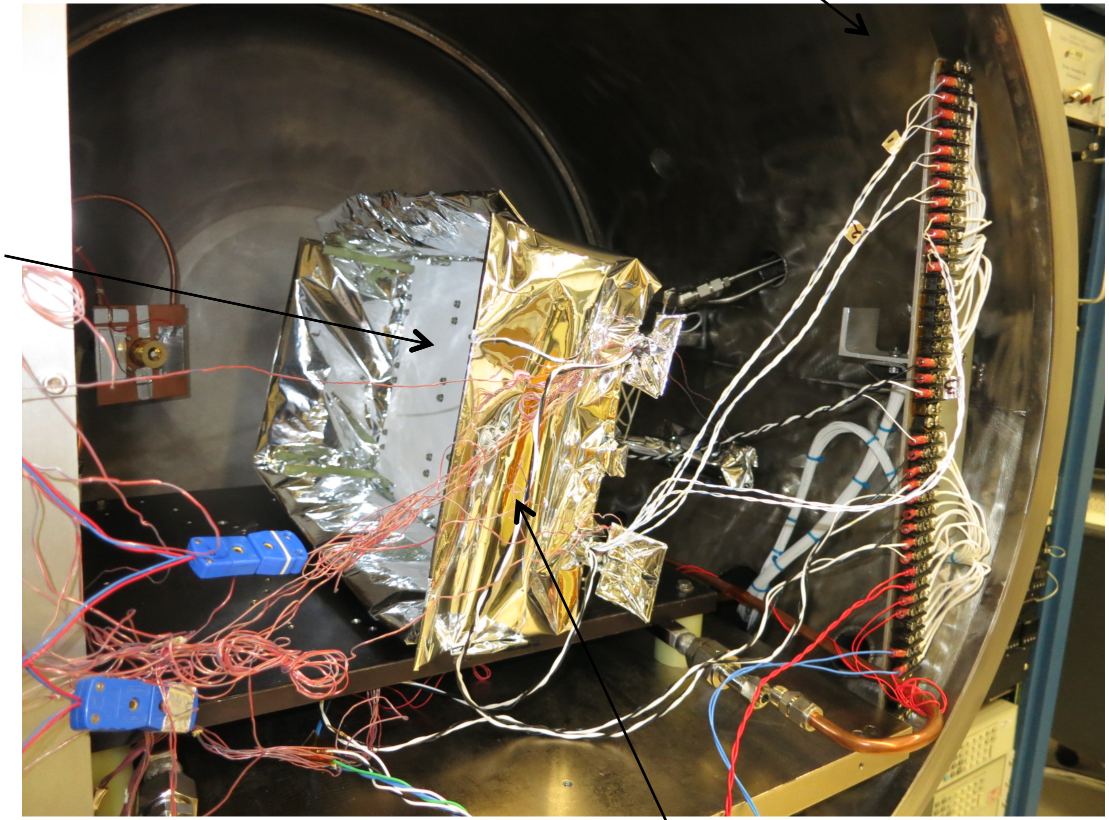


Mass of heat rejection system: 0.99 kg

APS Modification

Vacuum Chamber

Radiator



Ethane Heat Pipe in Reflux Mode

MLI Shielding

APS Modification

- Thermal Test Results

	Temperature (˚C)
Radiator	-25.0
TEC Cold Side	-87.1
Ethane Heat Pipe/Copper Strap Interface	-84.5
Copper Strap/Detector Assembly Interface	-83.3

TEC current (total)	5 A
TEC voltage	5 V
TEC power (total)	25 W

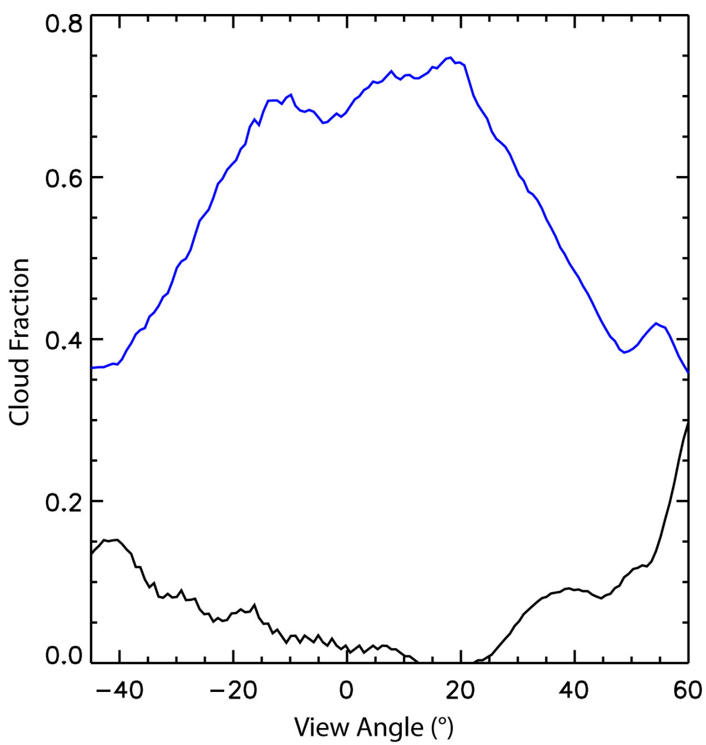
APS Modification

- **Simple 4-stage TEC cooling system provides adequate performance for APS**
- Thermal testing verified SWIR heat rejection system thermal performance
- Using indium foil as thermal interface material at following interfaces will decrease thermal resistances and achieve colder temperature at detector assembly
  - TEC and radiator
  - TEC and cold plate
  - Ethane heat pipe and cold plate
  - Ethane heat pipe and copper strap
- Improving MLI insulation for TEC, cold plate, ethane heat pipe and copper strap will decrease parasitic heat load and achieve colder temperature at detector assembly
- Shorter copper strap and larger number of copper foils will decrease thermal resistance and achieve colder temperature at detector assembly

APS-like Retrieval Approach

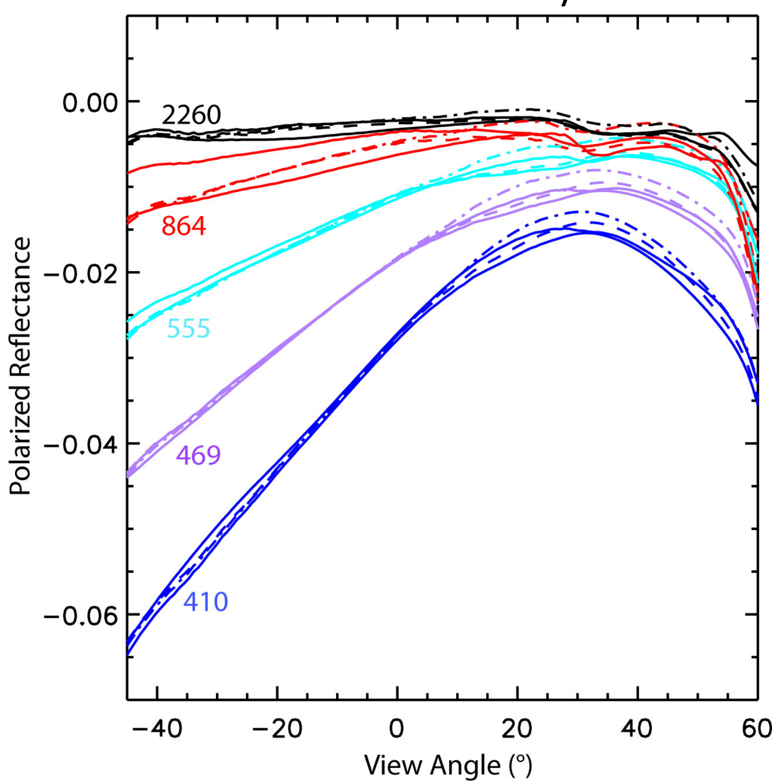
APS-like Retrieval Approach

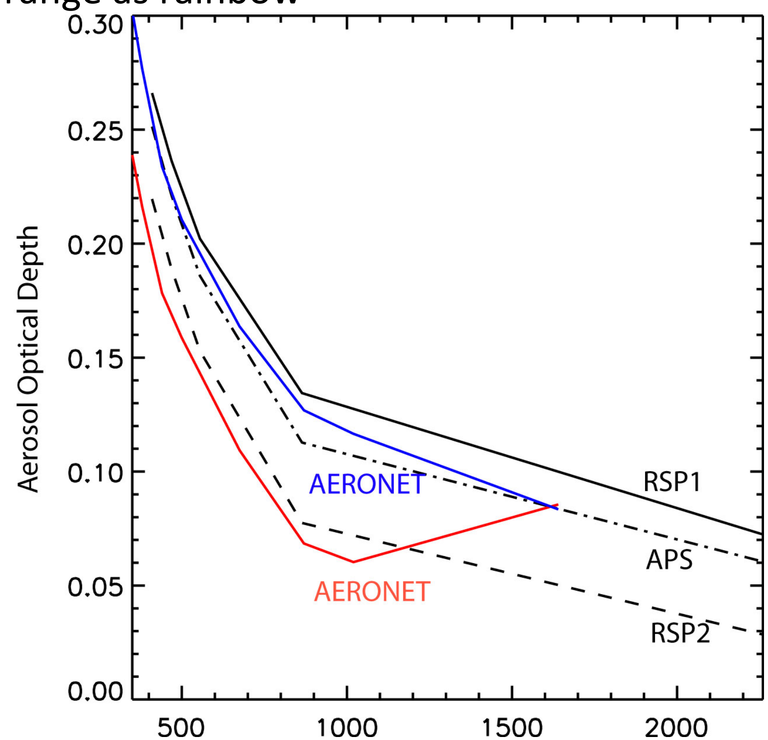
- **A scanner such as the RSP, or the Glory APS, has a ground pixel size that increases as a function of (roughly) $\cos\theta v^{-2}$.**
- Retrievals need to explicitly account for view angle cloud fraction variations.
- For broken cumulus, cloud fraction can (and does) decrease, or increase with view angle depending on whether the field is centered on a clear, or cloudy scene.



APS-like Retrieval Approach

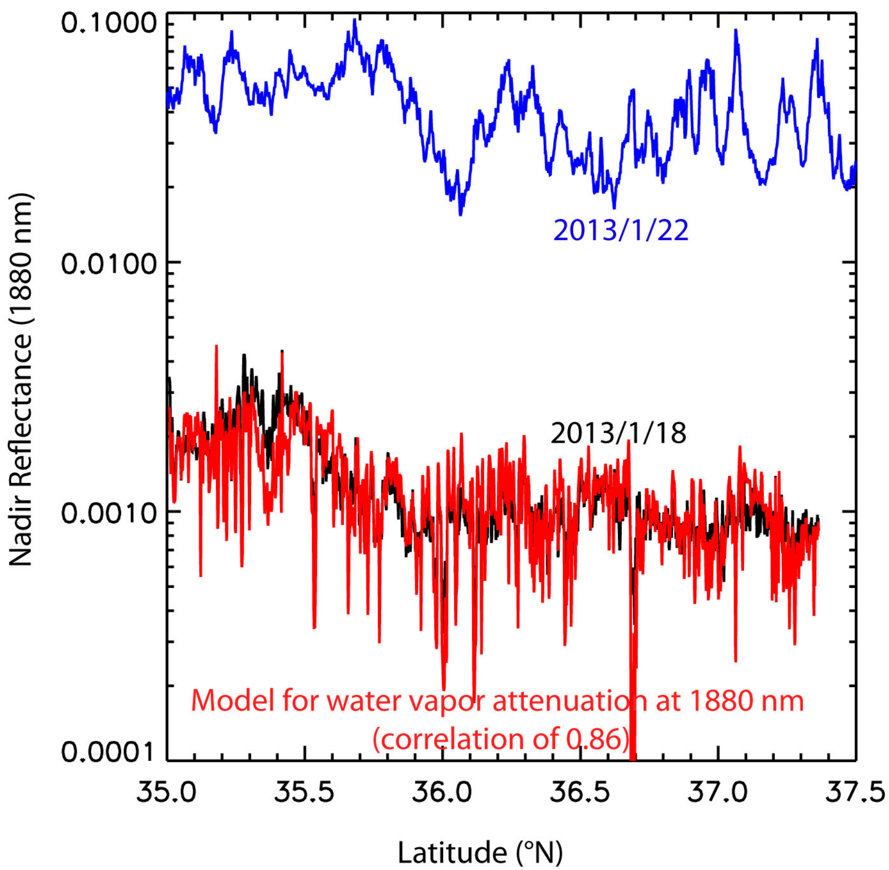
- **The example below is for the less cloudy scene from the previous slide**
- **Things to note:**
  - The lines overlaying the left hand figure show what happens when the accumulation/coarse mode optical depths are reduced by 50%
  - Cloud droplet size is 5 μm but could be anywhere from 4-6 μm
  - 864 nm is most sensitive to accumulation mode at side-scattering angles
  - Coarse mode sensitivity is in same angular range as rainbow

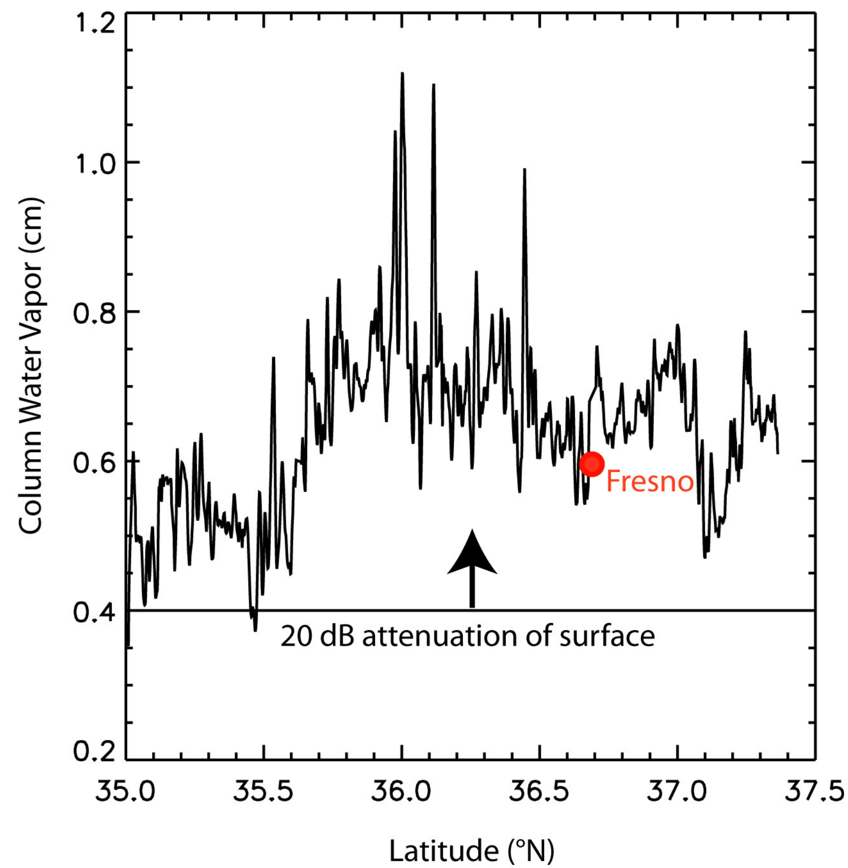




APS – cirrus band

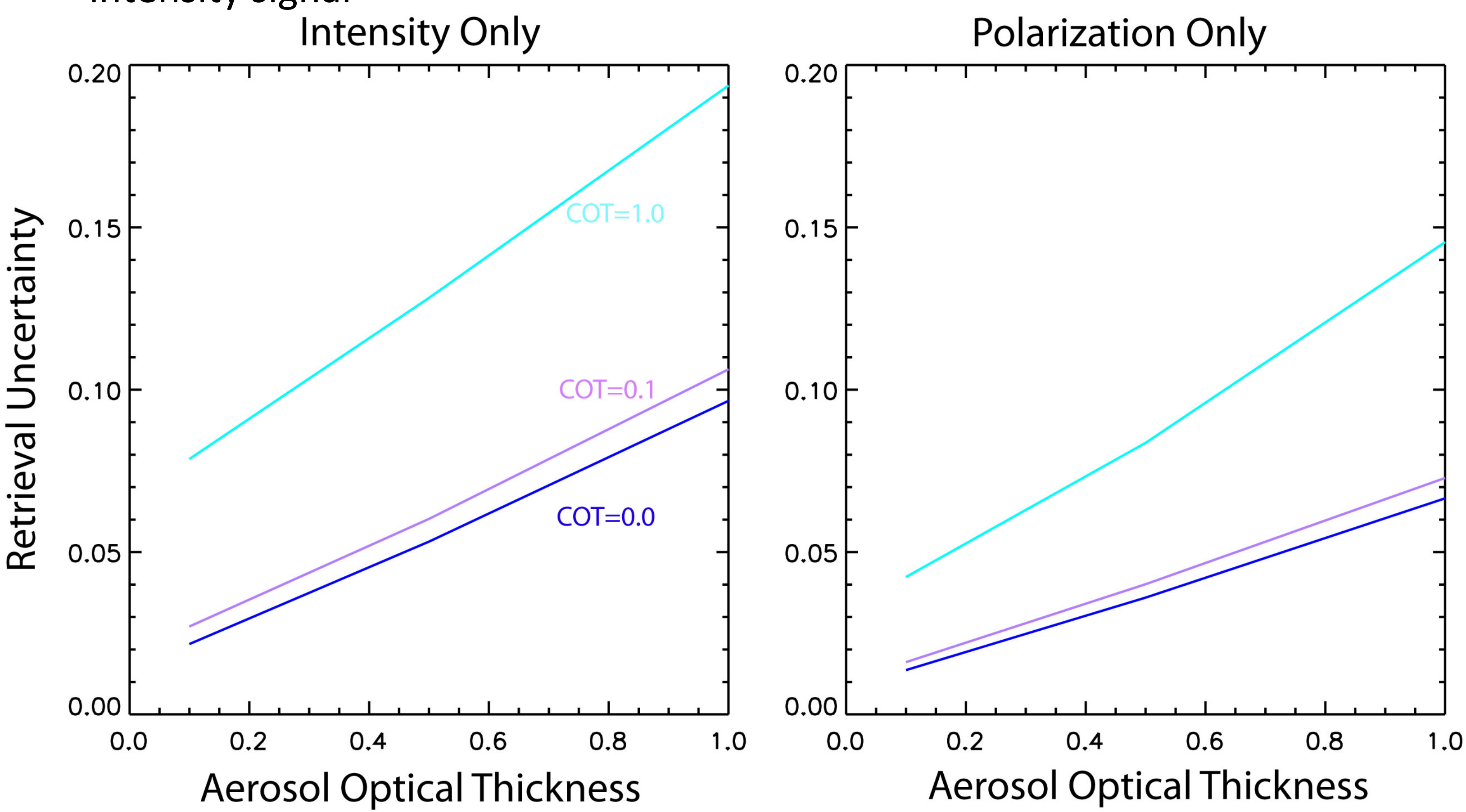
- **Evaluate screening of surface at 1880 nm.**
  - With more than 0.4 precipitable cm there is x100 attenuation of the surface.
  - Evaluation used RSP band, which is wide, but has no out of band.
  - Out of band characterization and control is as, if not more, important than bandwidth.





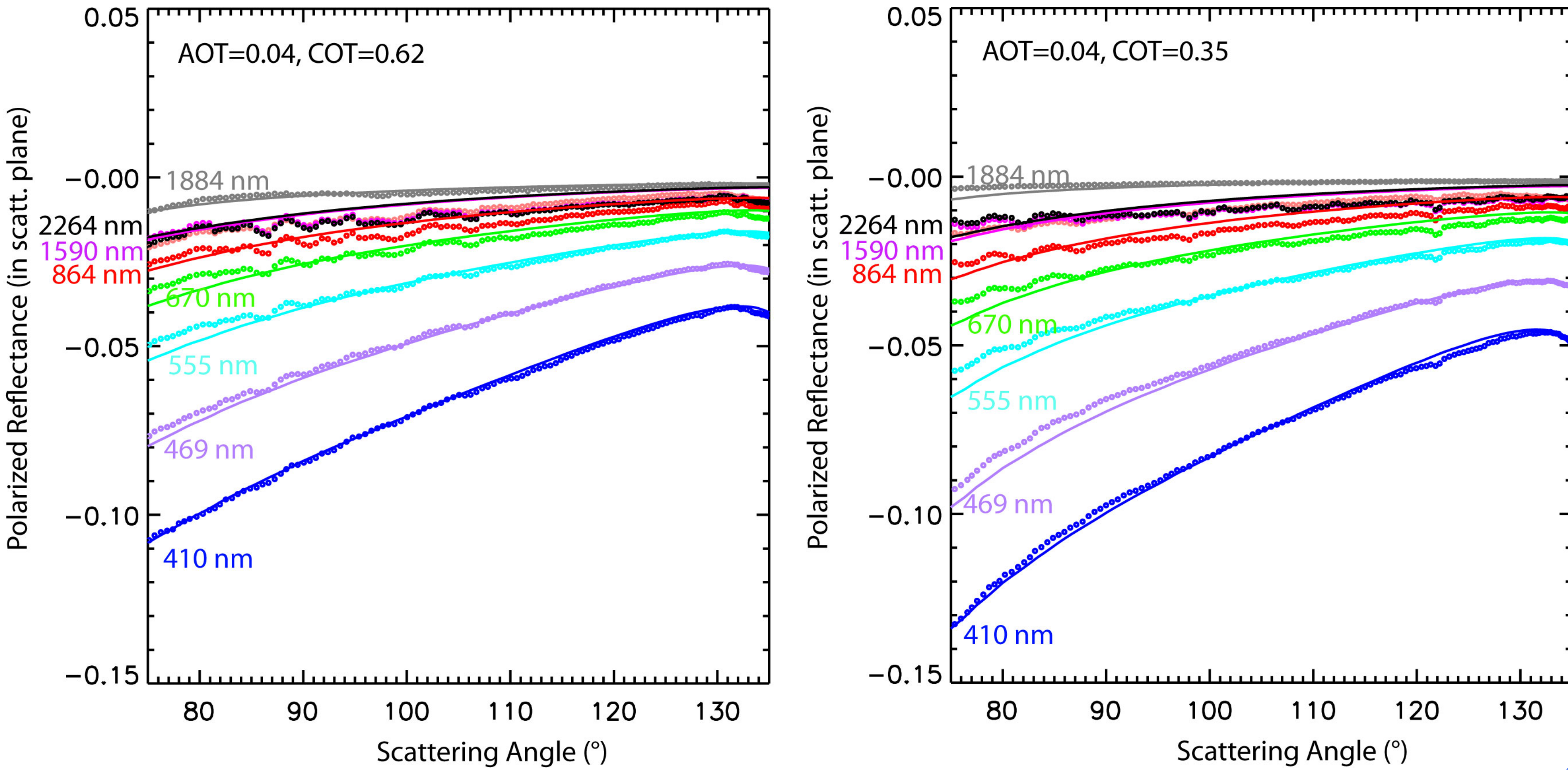
APS-like Retrieval Approach

- **Cirrus clouds primarily attenuate the polarized signal from aerosols and molecules lower in the atmosphere.**
  - They do not generate much polarization themselves.
  - They do attenuate the aerosol signal and contribute significantly to the total intensity signal



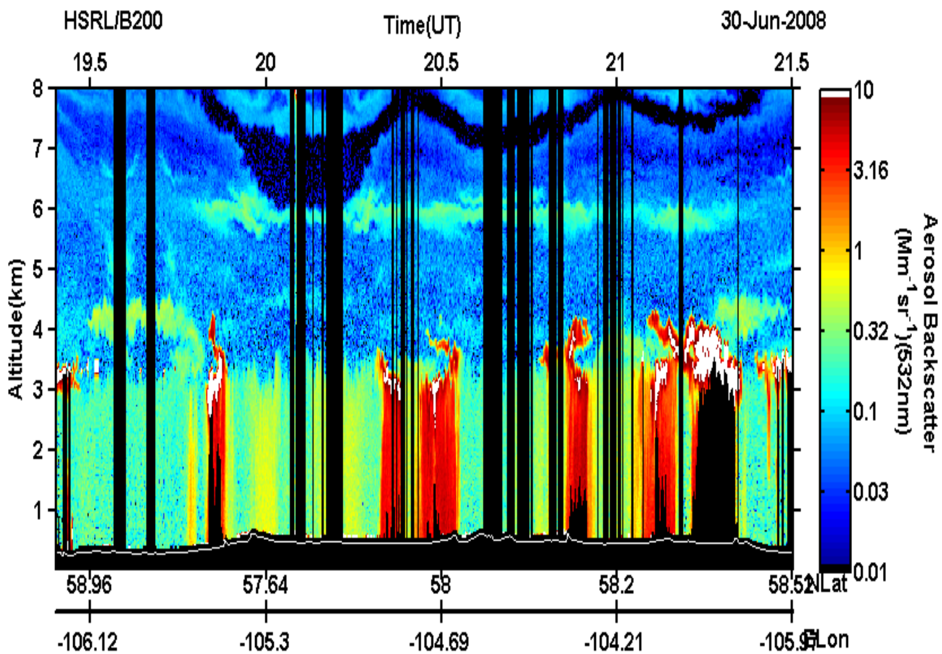
APS-like Retrieval Approach

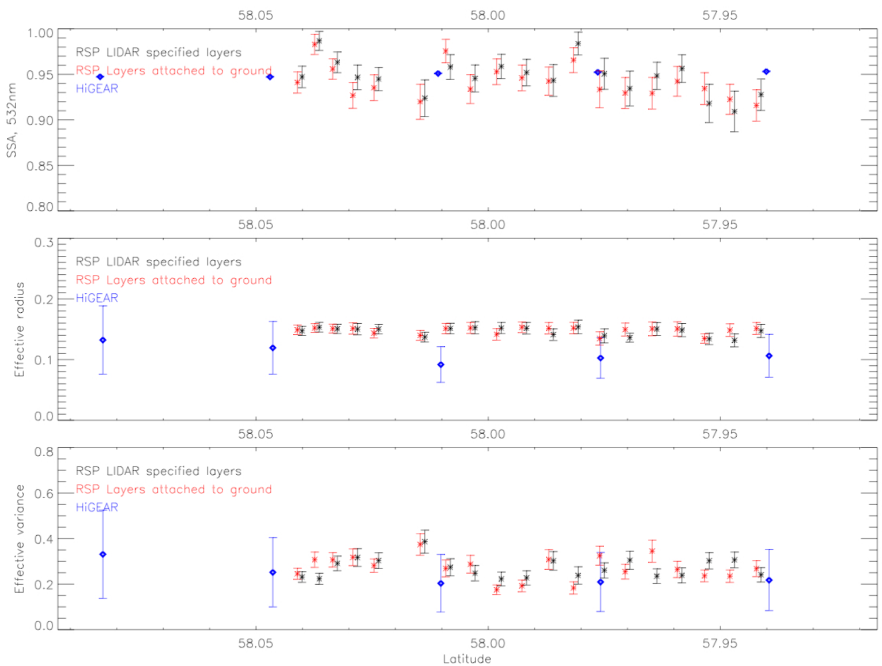
- **In the case shown aerosols are more homogeneous than cirrus.**
  - Cirrus optical thickness larger than aerosol, but aerosols still detectable (uncertainty ~ 50% at AOT of 0.04)
  - Total intensity has cloud contributions that are larger than that from aerosol and do not contribute to the aerosol retrieval



Combining Active and Passive

- **There are a lot of different ways to combine active (lidar) and passive (polarimeter) data.**
  - The best way of getting the most out of multi-angle data is using optimal estimation methods, which require iterative searches.
  - The addition of vertical information has no cost penalty in terms of computations provided a self-adjoint (e.g. Doubling/adding, VLIDORT etc.) calculation is used since the vertically resolved radiation field and its interactions with clouds and aerosols is calculated anyway.

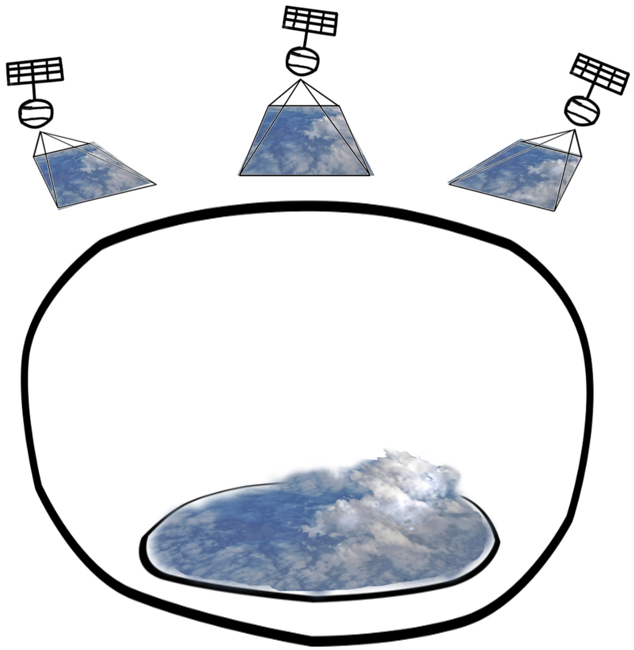




Combining Active and Passive

Cloud representation:

Three-dimensional cloud



Consider 3D retrievals to extend coverage to broken cloud fields

Solver 3D VRTE

- SHDOM [Evans,1998 and 2014]
- Adjoint derivative [Martin, 2014]

Inverse problem

- Retrieval of 1D cloud properties [Evans, 2008]
- Stability and data requirements?

How do we represent clouds for doing 3D retrievals of the atmosphere and surface?

Combining Active and Passive

Adjoint method:

scalable adjustments to 3D properties

Iterative minimization of the misfit function with only two calls to the 3D VRTE (per wavelength):

- Solve the 3D VRTE once to compute the residual
- Solve the adjoint 3D VRTE once calculate the derivative
- Solve a system of linear equations for the parameter adjustment

Procedure scales to very large problems with . . .

- Many measurement constraints
- Many unknown cloud, aerosol and surface properties

Adjoint method makes 3D retrievals with the 3D VRTE worth discussing

- Future project 1: Test derivative calculations and performance
- Future project 2: Synthetic retrievals and inverse problem analysis

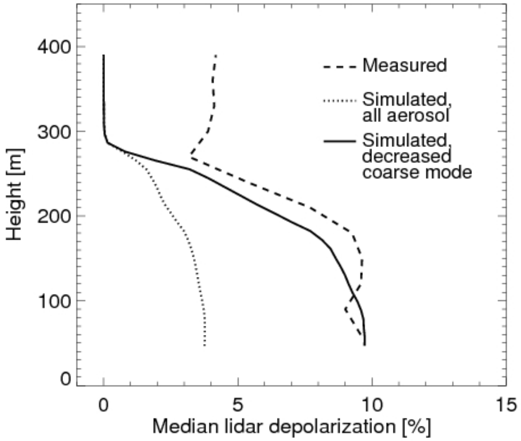
Probably still can't do 3D cloud retrievals on your smart phone.

Potential for Expanded Future Use of Observational System Simulation Experiment (OSSE) Approach?

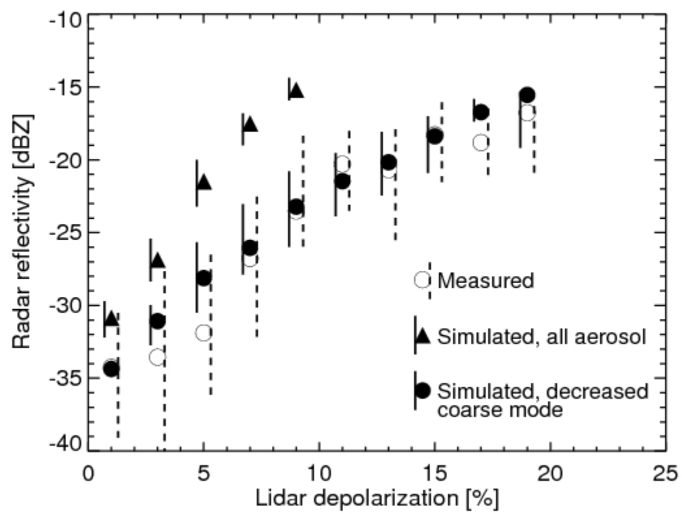
- **Context**
  - optimization of multi-instrument platform choices
  - target aerosol-cloud-precipitation conditions of interest
  - large-eddy simulations representing range of target conditions
- **Considerations**
  - bin microphysics probably required, especially for drizzle, rain or ice
    - drizzle, rain and ice size distributions generally not exponential and often not unimodal
    - droplet dispersion distribution not obtained with diagnostic bulk scheme
  - forward simulation skill should be tested in complex natural conditions that are well constrained observationally
    - may pose unique requirements on field experiment measurement suite
      - supermicron aerosol
      - ice particle properties
    - simulations can't be trusted without detailed comparison to measurements
      - too many uncertainties in aerosol-cloud-precip processes
      - special demands posed by forward simulation (e.g., reflectivity)

Influence of Humidified Aerosols on Lidar Depolarization Below Ice-Precipitating Arctic Stratus

- **Question**: why are lidar depolarizations < 20% (often associated with drizzle or rain) commonly observed beneath ice-precipitating clouds in the Arctic?
- **Hypothesis**: depolarization signal from ice is reduced by scattering from humidified aerosol
- **Approach**: use large-eddy simulations with realistic ice size distributions (Fridlind et al., *JAS*, 2012) to calculate depolarization resulting from mixture of aerosol and ice below cloud
- **Results**: humidified aerosol can explain observed covariance of lidar depolarization and radar reflectivity, as well as prominent reduction of depolarization with height
- **Future work**: determine whether drizzle can be distinguished from humidified aerosol owing to differing influences on lidar depolarization profile (see van Diedenhoven et al., *JGR*, 2009)
- **Publication**: B. van Diedenhoven, A. M. Fridlind, and A. S. Ackerman, *J. Appl. Meteorol. Climatol.,* doi:10.1175/JAMC-D-11-037.1, 2011



When coarse mode aerosol is realistically sparse, calculations match mean depolarization below cloud (*above*) and the point-wise correlation with cloud radar reflectivity (*below*). Multiple scattering not computed, which impairs comparison in cloud (> 280 m, *above*).



Summary

- APS is a mature design that has already been built and has a TRL of 7
- Algorithmic and retrieval capabilities continue to improve and make better and more sophisticated used of the data.
- Adjoint solutions, both in 1D and 3D are computationally efficient and should be the preferred implementation for the calculation of Jacobians (1D), or cost-function gradients (3D).
- Adjoint solutions necessarily provide resolution of internal fields and simplify incorporation of active measurements in retrievals, which will be necessary for a future ACE mission.
- Its best to test these capabilities when you know the answer: OSSEs that are well constrained observationally provide the best place to test future multi-instrument platform capabilities and ensure capabilities will meet scientific needs.